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Detection of Deteriorating Patients on Surgical Wards Outside the ICU by an Automated MEWS-based Early Warning System With Paging Functionality

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Background: The establishment of early warning systems in hospitals was strongly recommended in recent guidelines to detect deteriorating patients early and direct them to adequate care. Upon reaching predefined trigger criteria, Medical Emergency Teams (MET) should be notified and directed to these patients. The present study analyses the effect of introducing an automated multiparameter early warning score (MEWS)-based early warning system with paging functionality on 2 wards hosting patients recovering from highly complex surgical interventions.

Methods: The deployment of the system was accompanied by retrospective data acquisition during 12 months (intervention) using 4 routine databases: Hospital patient data management, anesthesia database, local data of the German Resuscitation Registry, and measurement logs of the deployed system (intervention period only). A retrospective 12-month data review using the same aforementioned databases before the deployment of the system served as control. Control and intervention phases were separated by a 6-month washout period for the installation of the system and for training.

Results: Data from 3827 patients could be acquired from 2 surgical wards during the two 12-month periods, 1896 patients in the control and 1931 in the intervention cohorts. Patient characteristics differed between the 2 observation phases. American Society of Anesthesiologists risk classification and duration of surgery as well as German DRG case-weight were significantly higher in the intervention period. However, the rate of cardiac arrests significantly dropped from 5.3 to 2.1 per 1000 admissions in the intervention period ($P < 0.001$). This observation was paralleled by a reduction of unplanned ICU admissions from 3.6% to 3.0% ($P < 0.001$), and an increase of notifications of critical conditions to the ward surgeon. The primary triggers for MET activation were abnormal ECG alerts, specifically asystole (n = 5), and pulseless electric activity (n = 8).

Conclusion: In concert with a well-trained and organized MET, the early deterioration detection of patients on surgical wards outside the ICU may be improved by introducing an automated MEWS-based early warning system with paging functionality.

Keywords: automated track and trigger system, early warning scores, medical emergency team, patient safety

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The IGS system hardware was granted over the study period by Philips, Hamburg, Germany.

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In their EuSOS study, Pearse et al. showed a 4% mortality rate of surgical patients in Europe[1] with a 8% admission rate to intensive care units (ICU). Far more alarming is the fact that 73% of all surgical patients who died were never admitted to an ICU. Therefore, reducing the failure to rescue (FTR) rate, defined as death after a major postoperative complication,[2] is a major issue of quality management programs.[3] However, the majority of patients show signs of deterioration before cardiac arrest occurs.[4,5] Ward et al showed that hospitals with low FTR had significantly more staffing resources, than high FTR hospitals and simply hiring an intensivist to run a closed ICU will never reduce the FTR rate.[3,6]

In Europe, implementation of Medical Emergency Teams (MET)[7,8] was associated with a decrease in cardiopulmonary arrests, unplanned ICU admissions, and mortality in patients in hospital wards. Older meta-analyses doubt the efficiency of METs.[9] Unfortunately, METs alone will not reduce FTR rates when trigger criteria for their activation are not defined and actionable clinically. Familiarization of the staff outside ICUs and their training on MET activation criteria and resuscitation measures[10] are key factors for reducing FTR by METs.[11] Intensive training programs of the MET further enhance their success.[10,12] Nonetheless, merely improving this efferent leg of in-hospital emergency response is not sufficient for comprehensive patient care.[8,13]

The afferent leg of in-hospital emergency response, which describes the process until the emergency is recognized and the call has reached the MET, is just as important.[13] Indeed, Boniatti et al demonstrated higher mortality in patients after delayed MET response.[14] Quality rating of correctly detecting a patient's condition on wards showed marked differences between medical care provider's self-assessment and the appraisal by independent experts[15] and, thus, demanded improvement. Recent resuscitation guidelines recommend the implementation of early warning scores for prompt detection of deteriorating patients [16–18] by either using single parameter systems with only singular alert criteria,[19] or using more sensitive multiparameter systems, in which a series of physiologic parameters are aggregated to assess patient deterioration.[20,21] Implementation of Multiparameter Early Warning Scores (MEWS) charts (Table 1) on wards outside the ICU showed significant reductions in

TABLE 1. Rating Table of Physiologic Parameters According to National Early Warning Score[20]

	Score						
Physiological Parameters	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Respiration rate (1/min)		≤8	9–11	12–20		21–24	≥25
Oxygen saturations (%)	≤91	92–93	94–95	≥96			
Any supplemental oxygen				No		Yes	
Temperature (°C)	≤35.0		35.1–36.0	36.1–38.0	38.1–39.0	≥39.1	
Systolic BP, mmHg	≤90	91–100	101–110	111–219			≥220
Heart rate (1/min)	≤40		41–50	51–90	91–110	111–130	≥131
Level of consciousness				A			V, P, U
Team concern				No			Yes

Level of consciousness: Alert (A), unresponsiveness to voice (V), unresponsiveness to painful stimuli (P), or unconscious (U).

the incidence of cardiac arrest calls.[22] However, merely 68% protocol compliance with manual MEWS charts were reached.[23] One possible solution for this problem was given by Bellomo et al[24] who showed that a MEWS-based electronic automated vital signs monitoring system increased survival of patients receiving MET treatment, and decreased time required for vital signs measurement and recording. A follow up-study[25] even showed significantly reduced cardiac arrests and mortality levels.

The present study set out to evaluate the effect of deploying an automated MEWS-based early warning system with paging functionality, including telemetry on an at-risk population recovering in wards outside the ICU from complex surgical interventions.

METHODS

After approval of the institutional review board (EK DD 291072016), data from 4 clinical routine databases were collected and analyzed over two 12-month periods. The study is registered under ClinicalTrials.gov (NCT03461133).

On July 1, 2016, an automated MEWS-based early warning system with paging functionality [IntelliVue Guardian Solution (IGS), Philips, Hamburg, Germany] was installed on 2 surgical wards with 56 beds in total. Each ward had 2 spot check monitors for measurement rounds and 4 sets of cableless remote controlled vital signs monitoring devices as earlier described by Subbe et al.[25] One set of cableless remote controlled vital signs monitoring devices consists of a respiratory pod, a pod for measuring SpO2 and a pod for non-invasive blood pressure. If applied, they were all attached at once. The wearable measurement devices were designed not to interfere with ambulation or with physical therapy. During the first 2-month period following IGS deployment, medical staff received intense training on the handling of the IGS system and wireless devices before activation.

All measurements from the monitors and cableless devices were transmitted via wireless local area network to a central server connected to the hospital data network and to a paging server [Digitaler Anruf- und Kommunikatiosserver (DAKS), Siemens, Erlangen, Germany] for automated notification to the dedicated ward physician during daytime, or the physician on call supervising several wards at nighttime. All notifications were sent via text message to custom DECT phones, providing information on patient room and bed numbers as well as the current MEWS score and the time over which it changed.

Table 1 shows the electronically implemented MEWS scoring sheet. The handling and escalation/de-escalation-protocol for measurement intervals and devices is given in Figure 1. Measurement rounds were performed at least twice daily using spot check monitors. Text prompts on the spot check monitors directly advised the nurses according to the handling protocol. In the event that a patient had a MEWS of 1 to 4, the nurse in charge was informed and the next measurement was scheduled in 4 to 6 hours. The use of cableless sensors was optional; they were only used for those patients if the staff on the ward had a higher workload. If MEWS was 5 to 6, the ward physician and the nurse in charge were informed in parallel. Cableless sensors were always attached to those patients and the next measurement was scheduled in 1 hour. According to the protocol, the frequency of measurements was adapted to the patient's condition. When the MEWS reached ≥7, the ward physician was automatically paged to attend to the deteriorating patient. It was to his discretion to call the MET if necessary. As the mobile pods just measure within their predefined intervals, the system would oversee deteriorating conditions between the predefined intervals. Hence, continuous measurements of oxygen saturation and blood pressure (15-minute intervals) were attached (IntelliVue MP2, Philips, Hamburg, Germany) in the condition MEWS ≥7. In case of a life-threatening condition, the MET could directly be called by a button on the monitor at any given MEWS by any team member.

Additionally, a dashboard of all patients on both wards with their MEWS and underlying physiologic parameters was continuously displayed on a monitor in both the central nurses' station and in the attending surgeons' rooms. From these terminals, the individual measurement intervals of cableless devices were remotely controlled and an additional dashboard function allowed for an overview and trending of the physiologic condition of all patients.

Within the control phase, trigger criteria for MET response were:[26] (impending) airway obstruction, respiration frequency

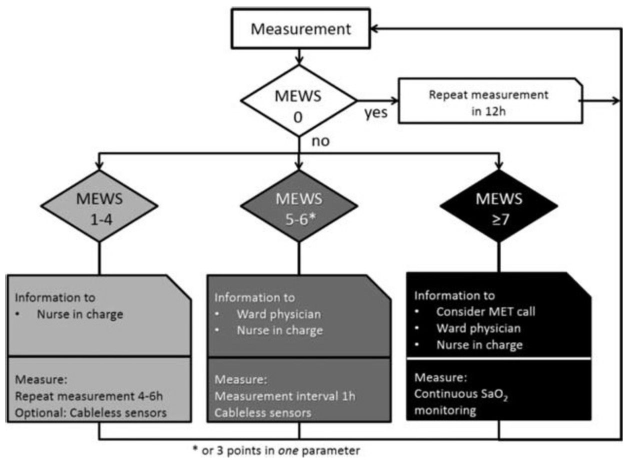

FIGURE 1. Flowchart for patient condition adapted measurement, handling of IGS components, and communication.

TABLE 2. Patient Characteristics Absolute Number (Percent) or Mean Values ± SD

Parameter	Class/Unit	Groups		P
		Reference (n = 1 896)	Intervention (n = 1 931)	
Sex	Female	682 (36.0%)	685 (35.5%)	—
Age, y		64.6 ± 15.7	65.2 ± 14.8	—
ASA class	I	99 (5.2%)	47 (2.4%)	<0.001
	II	542 (28.6%)	442 (22.9%)	
	III	1192 (62.9%)	1307 (67.7%)	
	IV	60 (3.2%)	129 (6.7%)	
	V	3 (0.2%)	6 (0.3%)	
NYHA class	No heart insufficiency	1413 (74.5%)	1425 (73.8%)	—
	I	104 (5.5%)	127 (6.6%)	
	II	260 (13.7%)	268 (13.9%)	
	III	110 (5.8%)	100 (5.2%)	
	IV	9 (0.5%)	11 (0.6%)	
CCS	No angina pectoris	1801 (95%)	1816 (94%)	—
	I	48 (2.5%)	69 (3.6%)	
	II	33 (1.7%)	27 (1.4%)	
	III	9 (0.5%)	11 (0.6%)	
	IV	5 (0.3%)	8 (0.4%)	
Urgency	Regular surgery	1504 (79.3%)	1512 (78.3%)	—
	Urgent 24 h	231 (12.2%)	214 (11.1%)	
	Urgent 2 h	142 (7.5%)	184 (9.5%)	
	Immediate	19 (1%)	21 (1.1%)	
Duration surgery, h		2.7 ± 3.0	3.0 ± 2.4	0.003
G-DRG case weight*		3.037 ± 5.240	3.398 ± 6.125	0.003

P values from Fisher exact test or Mann-Whitney U test. American Society of Anesthesiologist (ASA) classification of comorbidity; New York Heart Association (NYHA) classification of heart insufficiency; Canadian Cardiovascular Society (CCS) classification of angina pectoris.

*G-DRG case weight represents the relative resource utilization for patient care in comparison to national mean (=1.000).

<5/min or >36/min, cardiac arrest, heart rate <40/min or >140/min, systolic blood pressure <90 mm Hg, concerns about the patient's condition independent from measurements, newly altered mental status and/or drop of GCS by >2 points. Meanwhile, in the intervention phase, there always was a clear physiologic trigger to notify the ward physician. It was to his discretion to call the MET.

Database Management

Deployment of the IGS was accompanied by data acquisition in 4 routine databases from July 1, 2016 to June 30, 2017. To avoid a Hawthorne effect,[27] data from the first 6 months of 2016 were excluded, representing the period during which the IGS system was deployed and staff were trained across both surgical wards. Data from the 12-month period from Januray 1, 2015 to December 31, 2015 served as control. Data on length of stay, ICU admissions, age, sex, survival, G-DRG-codes and case weight originated from the hospital information system (ORBIS, AGFA HealthCare, Bonn, Germany). Data on comorbidities were derived from the anesthesia information system (ANDOK, DATAPEC, Pliezhausen, Germany). Note that only the initial comorbidities of each case number were extracted from the anesthesia database in the event that >1 surgical procedure was performed per patient. The local dataset of the German Resuscitation registry[28] provided all data recorded during the MET response with or without cardiac arrest. In the intervention phase, the IGS database (Philips, Hamburg, Germany) also provided all data on MEWS and the individual physiologic parameters of each vital sign measurement. Aggregation of databases was conducted by use of the key variable "FALLNUMMER," which was part of all 4 databases.

Statistical Analysis

Datasets are presented as absolute number of patients with respective percentage per group or as parameter mean ± standard deviation. For comparisons of interval-scaled variables between the observation periods, 2-tailed, unpaired t tests were performed. Levene test was used to check these variables for Gaussian distribution. Nonparametric between group testing was achieved with 2-tailed Mann-Whitney U test. Additionally, the χ^2 test or Fisher exact test was applied to nominal-scaled data. To address the fact that patient condition was significantly poorer during the intervention period, for example, in terms of DRG-case weight, comorbidity, and surgical complexity, as indicated by duration of surgery (Table 2, SDC table 5, http://links.lww.com/SLA/B432) statistical comparisons between the 2 observation periods were completed regarding the respective G-DRG case weight as a statistical confounder in χ^2 analyses.

SPSS software (IBM SPSS statistics, version 24.0.0.1, Armonk, NY) was used for all calculations. In all statistical comparisons, significance was accepted with an error probability of $P < 0.05$.

RESULTS

A total of 3827 patients were acquired from the 2 surgical wards during the two 12-month observation periods. Although the control cohort contained 1896 patients, the intervention cohort had 1931 patients. Patient demographics and comorbidity are shown in Table 2 and SDC table 5, http://links.lww.com/SLA/B432. American Society of Anesthesiologists risk classification ($P < 0.001$) and duration of surgery ($P = 0.003$) as well as German DRG case weight ($P = 0.003$) were significantly higher in the intervention period. SDC table 6, http://links.lww.com/SLA/B432 summarizes the surgical procedures performed on patients included in this study.

MET calls, as depicted in Table 3, originated mainly from cardiopulmonary causes. Main causes of cardiac arrest were the non-shockable rhythms asystole and pulseless electric activity, but these

TABLE 3. Causes for Medical Emergency Team (MET) Calls and MET Response

Characteristic	Type	Groups: Reference (n = 18)	Groups: Intervention (n = 13)	*P*
Organ system Affected	Airway	0 (0.0%)	1 (7.7%)	—
	Breathing	2 (11.1%)	3 (23.1%)	
	Circulation	2 (11.1%)	4 (30.8%)	
	Cardiac arrest	10 (55.6%)	4 (30.8%)	
	Disability	2 (11.1%)	0 (0.0%)	
	Team concerned	2 (11.1%)	1 (7.7%)	
Availability of vital data	Systolic BP <90 mm Hg	1 (5.6%)	4 (30.8%)	0.024
	SaO2 <90%	1 (5.6%)	3 (23.1%)	
	Unknown	16 (88.9%)	6 (46.2%)	
Detection of Emergency	Observation by staff	17 (94.4%)	6 (46.2%)	0.004
	Monitor alert	1 (5.6%)	7 (53.8%)	
ECG	Sinus rhythm	4 (22.2%)	5 (38.5%)	—
	Arrhythmia	1 (5.6%)	1 (7.7%)	
	Ventricular tachycardia*	0 (0.0%)	1 (7.7%)	
	Ventricular fibrillation*	1 (5.6%)	0 (0.0%)	
	Pulseless electric activity†	5 (27.8%)	0 (0.0%)	
	Asystole†	4 (22.2%)	4 (30.8%)	
	Not assessable	3 (16.7%)	2 (15.4%)	
Respiration	Normal	5 (27.8%)	4 (30.8%)	—
	Dyspnea	2 (11.1%)	6 (46.2%)	
	Gasping respiration	3 (16.7%)	0 (0.0%)	
	Apnea	7 (38.9%)	3 (23.1%)	
	Hyperventilation	1 (5.6%)	0 (0.0%)	
Duration event to team on scene		5.3 ± 1.7	4.0 ± 1.0	—
Total duration of MET mission		32.2 ± 14.7	35.2 ± 17.2	—
Epinephrine applied (total mg per cardiac arrest case)		3.9 ± 3.0	3.3 ± 1.5	—

Data source: Local data from German Resuscitation registry for in hospital emergencies.[40] *P* values from Fisher exact test or independent sample *t*-test. BP indicates blood pressure.
*Shockable ECG rhythm.
†Non-shockable ECG rhythm.

showed no differences between control and intervention groups. Significant differences were found in the availability of physiologic data at MET arrival with a higher proportion of blood pressure and saturation measurements ($P = 0.024$) in the intervention group. As expected, patient deterioration was more often detected in this group by monitor alert than by staff observation ($P = 0.004$). No differences were detected with regard to MET response time, total duration of MET, and patient encounter, or the dosage of prescribed epinephrine per case of cardiac arrest (Table 3).

No false-positive MET alarms were observed, and this can be partly because of the fact that the trigger criterion "concerns about the patient's condition" in the control phase as well as clear physiologic triggers during the intervention phase existed. Hence, in every case, there was a clear cause for the MET calls.

The rate of cardiac arrests on the wards (Table 4) dropped from 5.3 to 2.1 per 1000 admissions in the intervention period, which was statistically significant in the DRG-case weight adjusted analysis ($P < 0.001$). Risk ratios for the different types of emergency calls when implementing an automated MEWS-based early warning system with paging functionality are shown in Figure 2, which indicates a significant increase in notifications of critical conditions to the attending surgeon on the ward, whereas CPR calls significantly dropped (see also Figure 3). This observation was paralleled by a reduction of unplanned ICU admissions from 3.6% to 3.0%

TABLE 4. Effects of Electronically Supported MEWS on the Incidence of IHCA and Other Outcome Parameters

Parameter	Groups: Reference (n = 1896)	Groups: Intervention (n = 1931)	*P*
Calls emergency team—total	18	13	0.02
Calls per 1000 admissions	9.5	6.7	0.033
IHCA	10	4	<0.001
IHCA per 1000 admissions	5.3	2.1	<0.001
Critical MEWS (≥7)	n.a.	118	n.a.
Critical MEWS per 1000 admissions	n.a.	61.1	
Patient never admitted to ICU	1 129 (59.6%)	1 218 (63.1%)	—
ICU admission unplanned	69 (3.6%)	58 (3.0%)	<0.001
Lengths of hospital stay, days	14.7 ± 20.3	13.8 ± 17.9	—

P values from Fisher exact test weighted by individual G-DRG-case weight or independent sample *t* test. In the reference group, no MEW-scoring was done so data cannot be reported.

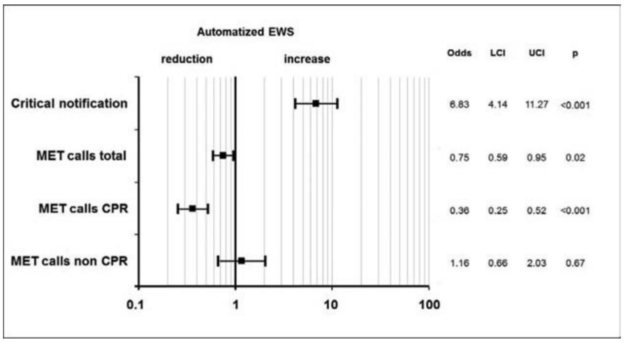

FIGURE 2. Risk ratios for the probability of Medical emergency team calls by implementing an automated MEWS-based early warning system with paging functionality with a first responder level by the ward physician. LCI indicates lower confidence interval; Odds, odds ratio; UCI, upper confidence interval.

($P < 0.001$) in the intervention period. Mortality as expressed as deaths 1000 G DRG case weight points did not differ between the groups (reference 8.5 vs intervention 8.8). No changes in DNR order policy or distribution were observed during the study period.

SDC table 7, http://links.lww.com/SLA/B432 shows the distribution of physiologic conditions that contribute to a critical notification when a MEWS of seven or higher is reached. These data identify a drop in oxygen saturation ≤91% and systolic blood pressure ≤90 mmHg as the leading problems that are consistently underscored by the data recorded from the MET (Table 3). Accordingly, it is shown that the mean score contribution of physiologic parameters in deteriorating patients (SDC figure 4, http://links.lww.com/SLA/B432) are oxygen saturation and blood pressure.

DISCUSSION

In 2015, our institution had a 30-day survival rate after in-hospital cardiac arrest (IHCA) of 26.4% versus 9.4% for the benchmark of the German Resuscitation Registry.[28,29] Nonetheless, the overall IHCA incidence per 1000 admissions of 1.7 was comparable to the benchmark of 1.9. International data indicate that 1–5 of 1000 patients admitted to hospitals suffer from IHCA during their stay.[30] Data from the United Kingdom national cardiac arrest audit database show an overall incidence of 1.6 cardiac arrests per 1000 admissions across 144 participating hospitals.[31] At first glance, data seem

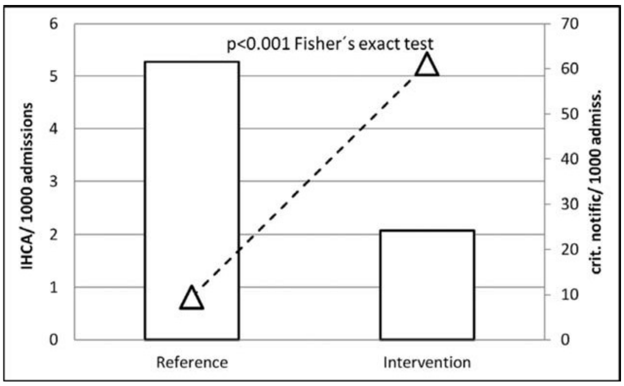

FIGURE 3. Relationship between increased system alert level and avoidance of IHCA. IHCA per 1000 admissions (bars) and critical notifications per 1000 admissions (triangles).

similar; however, comorbidity and complexity of the UK registry patient cohort are not reported and must be taken into consideration in any comparison. Taking into account the number of hospitals, one may assume that the mean DRG case weight of the patients in this database approximates 1 because the nationwide mean case weight is calculated to 1 to estimate the individual resource utilization per case. The present study shows an at risk cohort with 3-fold case complexity (table 2, SDC table 6, http://links.lww.com/SLA/B432).

Buist et al and others[5,32] indicate that early signs of patient deterioration exist but are routinely disregarded. We hypothesized that improving the sensitivity of the afferent leg of emergency detection on surgical wards[13] would increase the number of MET missions, but, at the same time, would decrease the incidence of IHCA. Therefore, an automated MEWS-based early warning system with paging functionality as described earlier by Subbe et al[25] was deployed in two surgical wards hosting a high risk patient population.

As patient comorbidity and surgical complexity significantly differed between the observation periods (Table 2), DRG-case weight was integrated in statistical analysis to control as a confounder.

The reasons for MET notifications in the present study are shown in Table 3. Main causes are respiration and circulation, which is well in line with reports from Pebderby et al,[33] Bannard-Smith et al,[34] and Boniatti et al.[35] Data from the automated MEWS-based early warning system (SDC figure 4, http://links.lww.com/SLA/B432) support these observations, and underscore the weight of oxygen saturation in the detection of deteriorating patients. Likewise, we could show that even in complex surgical patients the proportion of shockable to non-shockable ECG rhythms of 13.3% versus. 86.7% (Table 3) is comparable to nonsurgical or mixed cohorts.[31,36,37] Not too surprising was the observation that under an automated MEWS-based early warning system with paging functionality the number of notifications and the availability of physiologic data on arrival of the MET were significantly higher. In the UK, where MEWS charts are mandatory in patient care, MET notifications occur more rarely triggered by MEWS criteria as compared to other countries,[34] indicating that patient deteriorating may be recognized earlier in the UK and early intervention on the ward avoids MET notifications. One may assume that the same applies after deployment of an automated MEWS-based early warning system with paging functionality. The observed reduction of unplanned ICU admissions (Table 4) supports this assumption.

Delay in MET call as such,[14] as well as delay in defibrillation when indicated by >2 minutes, were associated with increased mortality.[37–39] From this perspective, deployment of an automated MEWS-based early warning system with paging functionality in our setting had no effect on time from detection of an emergency to the arrival of the MET on scene. Due to the building structure of our hospital, with widespread buildings MET response times are long. To mitigate this issue, we earlier reported on our training program[10] to enable staff on the wards to effectively bridge the time to MET arrival.

There is a 1.5 to 8 times increase of emergency notifications following the deployment of a MET, when alerting criteria are made more sensitive.[13,32] This effect on MET calls was seemingly absent in the chosen setting. As shown in Table 4, the number of critical notifications in the intervention phase, when MEWS exceeded 7, was 118. These notifications were first directed to the physician in charge on the ward, who then decided whether to address the patient deterioration himself or call the MET. In fact, an increase of the physician in charge notifications has taken place. However, this increase did not lead to an increase in MET calls in the intervention period, as the advanced deterioration detection led to the discovery of therapeutic solutions on the ward instead of calling the MET.

Owing to the retrospective character of the study, some limitations do exist. Prospective data acquisition would have enabled introducing new parameters not yet mapped in the used databases; however, permanent presence of a study team member might have affected the measurements. Furthermore, conclusions from the present study may merely be hypothesis generating and not causally.

As this article clearly demonstrates, sensitizing the afferent leg of detecting emergency situations in deteriorating patients on surgical wards is supported by deployment of an automated MEWS and may reduce the incidence of IHCA the FTR rate.

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